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EERO TECHNICAL REPORT NO. 33

PROJECT SERGIUS NARROWS - SUMMARY OF TESTS ON LIESNOI ISLAND, ALASKA, 1970

MAJ RICHARD H. GILLESPIE

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Livermore, California

An Activity of
U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION
Vicksburg, Mississippi

November 1971

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Preface

This report was prepared by the Engineer and Construction Division, U.S. Army Engineer Explosive Excavation Research Office (formerly the Nuclear Cratering Group). The report is a summary of cratering experiments on Liesnoi Island, Alaska, in 1970. The tests described were preliminary to the design of a channel rock excavation project being conducted by the Alaska District, U.S. Army Corps of Engineers.

The work described in the report was funded by the Office of the Chief of Engineers (OCE) Appropriation 96X3121, General Investigations.

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13. ABSTRACT

Project SERGIUS NARROWS, Liesnoi Island Tests, was executed during the period 8 June through 8 July 1970 in a granitic medium on Liesnoi Island, Alaska. The tests consisted of attempts to spring fifty-seven small diameter drill holes to accept cratering charges, then detonating the holes sprung successfully as cratering charges. The springing tests indicated that hole springing in an intermediate to high strength rock is not economical due to the high probability of hole failure. The cratering results are sketchy but tend to indicate that the cratering criteria developed for high strength rock is valid for the granitic medium of Sergius Narrows, Alaska.

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Abstract

Project Sergius Narrows was executed during the period 8 June through 8 July 1970 in a granitic medium on Leisnoi Island, Alaska. The tests consisted of attempts (1) to spring (enlarge) 57 small-diameter drill holes to accept cratering charges, and (2) to detonate successfully as cratering charges the holes sprung. The tests indicated that hole springing in an intermediate-to-high-strength rock is not economical due to the high probability of hole collapse. The cratering results are sketchy but tend to indicate that the cratering criteria developed for high-strength rock are valid for the granitic medium of Sergius Narrows, Alaska.

Contents

FIGURES (continued)

TABLES

EERO TECHNICAL REPORT NO. 33

PROJECT SERGIUS NARROWS – SUMMARY OF TESTS ON LIESNOI ISLAND, ALASKA, 1970

Introduction

PURPOSE

This report documents the series of tests conducted on Liesnoi Island, Alaska, as part of the Alaska Engineer District's Sergius Narrows Project. The design, implementation, and results of these cratering experiments in a saturated intermediate-and-high-strength rock[1] are described.

BACKGROUND AND OBJECTIVES

The Liesnoi Island tests were, in part, a carry-on of the hole springing* work accomplished in a granitic medium at the Buchanan Damsite in California.[2] It was envisioned that 5-in. holes would be drilled to various depths, the bottom of the hole sprung (enlarged) to a size large enough to accept a cratering charge, and the hole loaded and fired as a cratering detonation. All the experimental work was carried out by the U.S. Army Nuclear Cratering Group (NCG)† with the construction and operational support of the Alaska Engineer District (NPA). The major experimental work is summarized in the following paragraphs.

Briefly stated, the objectives of the experiments were:

(1) To determine the effectiveness of springing detonations for emplacement hole construction in an intermediate-to-high-strength rock medium.

(2) To obtain data regarding cratering characteristics in a submerged intermediate to high-strength rock medium.

(3) To develop criteria for the design of parallel rows of explosive charges to achieve directional blasting as was required for the excavation of Wayanda Ledge, in Sergius Narrows.

This experimental program represented a further step in developing the use of large chemical explosive charges for excavation projects. Initially, NCG was engaged in a joint venture with the AEC to investigate peaceful excavation applications of nuclear explosives, and most of the earlier cratering experiments were designed as chemical explosive "models" of nuclear experiments. As the joint program progressed, excavation with large chemical explosive charges appeared to have potential merit in itself, and emphasis in the experimental program gradually shifted to investigating

*Enlarging the bottom of a drill hole by successive detonations of small explosive charges.

†Since August 1971, the U.S. Army Engineer Explosive Excavation Research Office (EERO).

the use of more economical explosives and methods of emplacement.

The first project with the sole aim of creating an engineer facility with large chemical explosives was Pre-Gondola III Phase III.[3] This was followed by Project Tugboat,[4] which created a small craft harbor in coral on the island of Hawaii. With the apparent success of both Pre-Gondola and Project Tugboat, the next logical step was to find a project requiring removal of a competent rock medium that was water-saturated. A decision was made to attempt to design the explosive removal of portions of Wayanda Ledge as an alternate construction technique for the project to improve the Sergius Narrows navigation channel. In order to properly design the project, it was necessary to determine the cratering characteristics of the granitic medium in the Narrows. Further, in order to reduce the charge emplacement costs, it was determined that hole springing should be studied in the same medium as a method of emplacement cavity construction. It was for these purposes that the tests on Liesnoi Island were conducted.

PROJECT ORGANIZATION

The organization in effect during the planning and execution of the tests is shown in Fig. 1. In this organization the Test Manager had direct responsibility for planning and coordinating the execution of the tests, and the Technical Deputy develops the technical concept for the project and the scope of associated technical programs. For this project, Major R. H. Gillespie acted as both Test Manager and Technical Deputy. Other specific personnel assignments were as shown in Fig. 1.

Site Description

The location of Sergius Narrows is shown on the map in Fig. 2. The test site on Liesnoi Island in Sergius Narrows is shown on the map in Fig. 3. Liesnoi Island lies at the entrance to Sergius Narrows, and the nearest population center is the town of Sitka approximately 30 mi to the southeast. Figures 4, 5, and 6 are aerial views of the island.

The rocks in the vicinity of Sergius Narrows consist of metamorphosed sediments and intrusive igneous rocks. West of Suloia Point the metamorphic rocks consist of phyllite, greenschist, greenstone, and graywacke. East of Liesnoi Island the metamorphic rocks consist of amphibolite, gneiss, and minor marble. Intruded into the metamorphics are a series of igneous rocks that range from gabbro to granite. The rocks outcropping along Sergius Narrows are part of one of the plutons, and consist of hornblende tonalites.

The rocks in the area show a pronounced regional trend. Bedding in the metamorphics has a northwest trend. Igneous bodies are elongate in a similar direction. In addition, many of the major faults show a northwest trend.

The northwest trend of the regional geologic structure is emphasized by the topography. Differential weathering

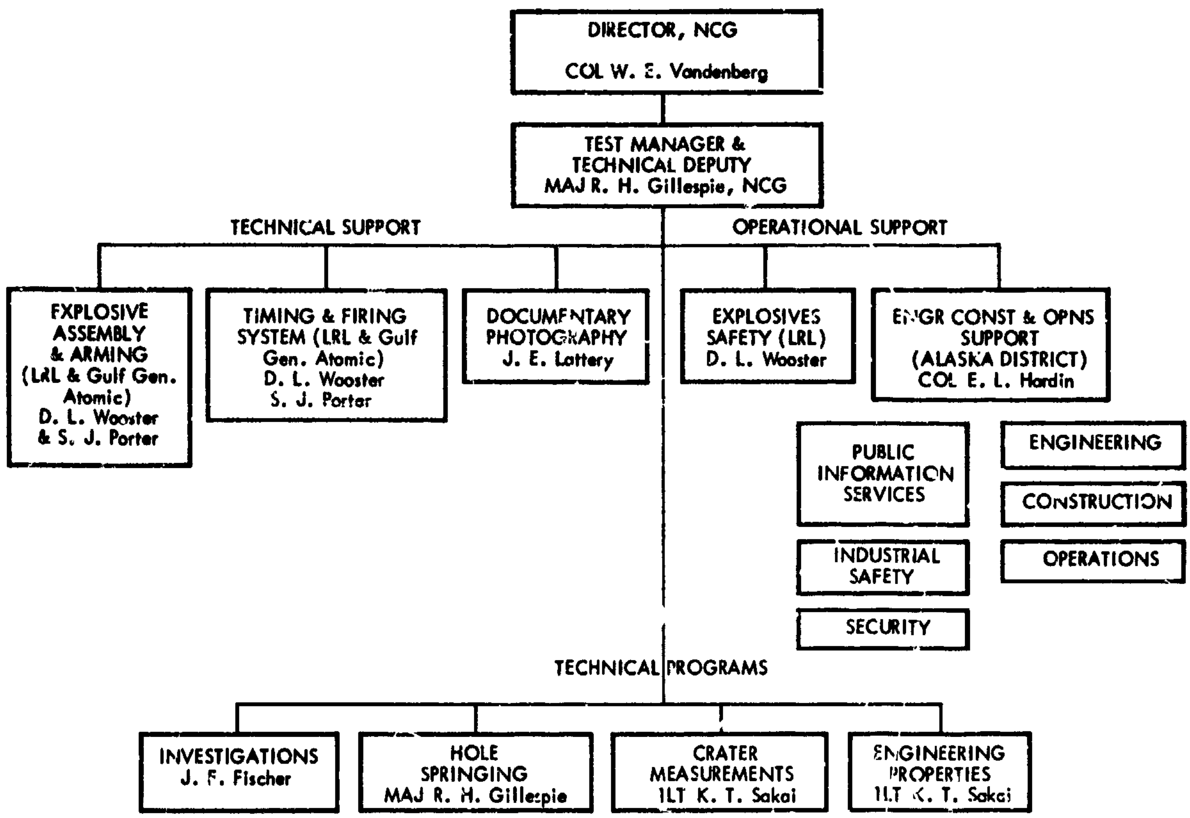


Fig. 1. Proje.., organization.

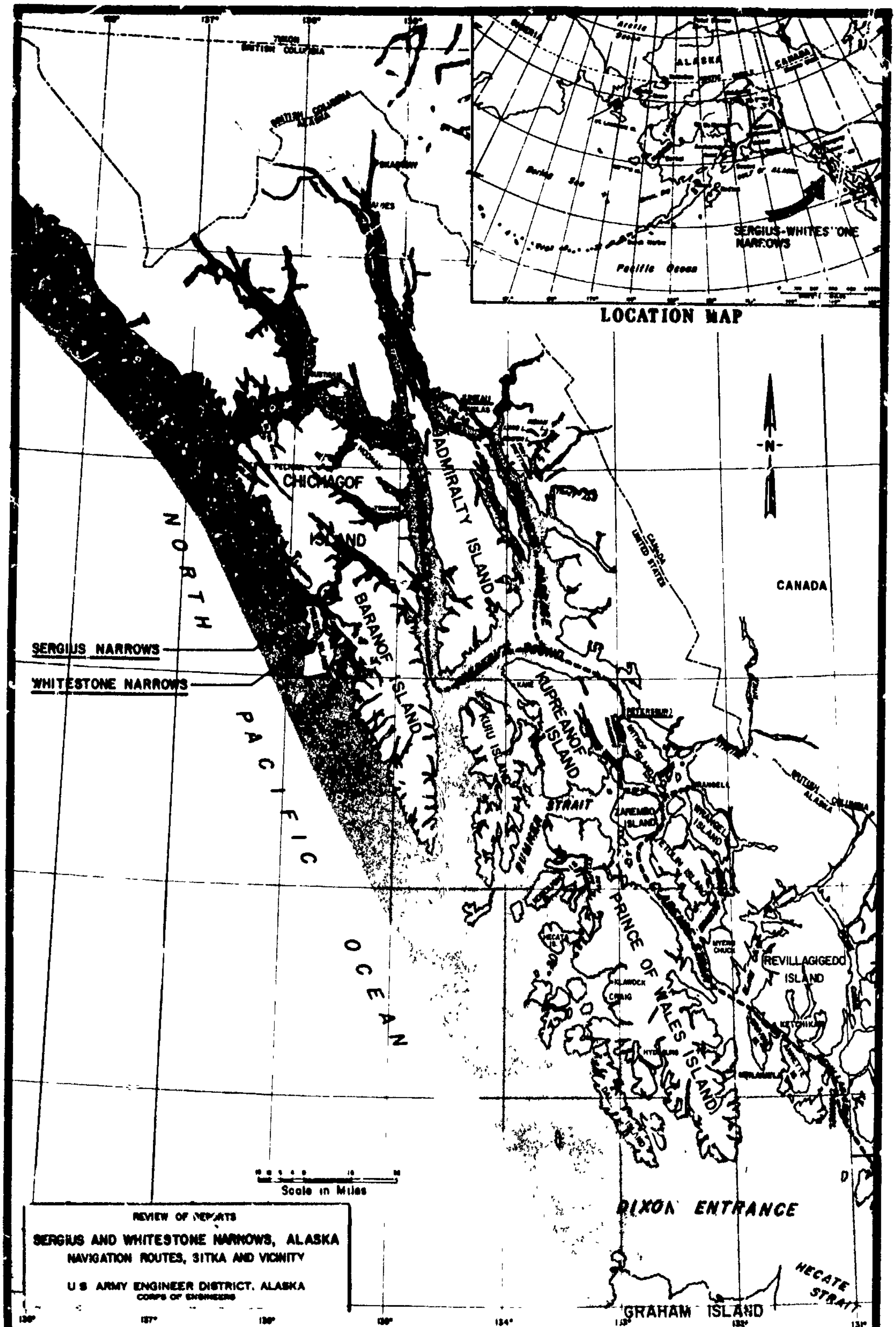


Fig. 2. Sergius Narrows location map (from Ref. 5).

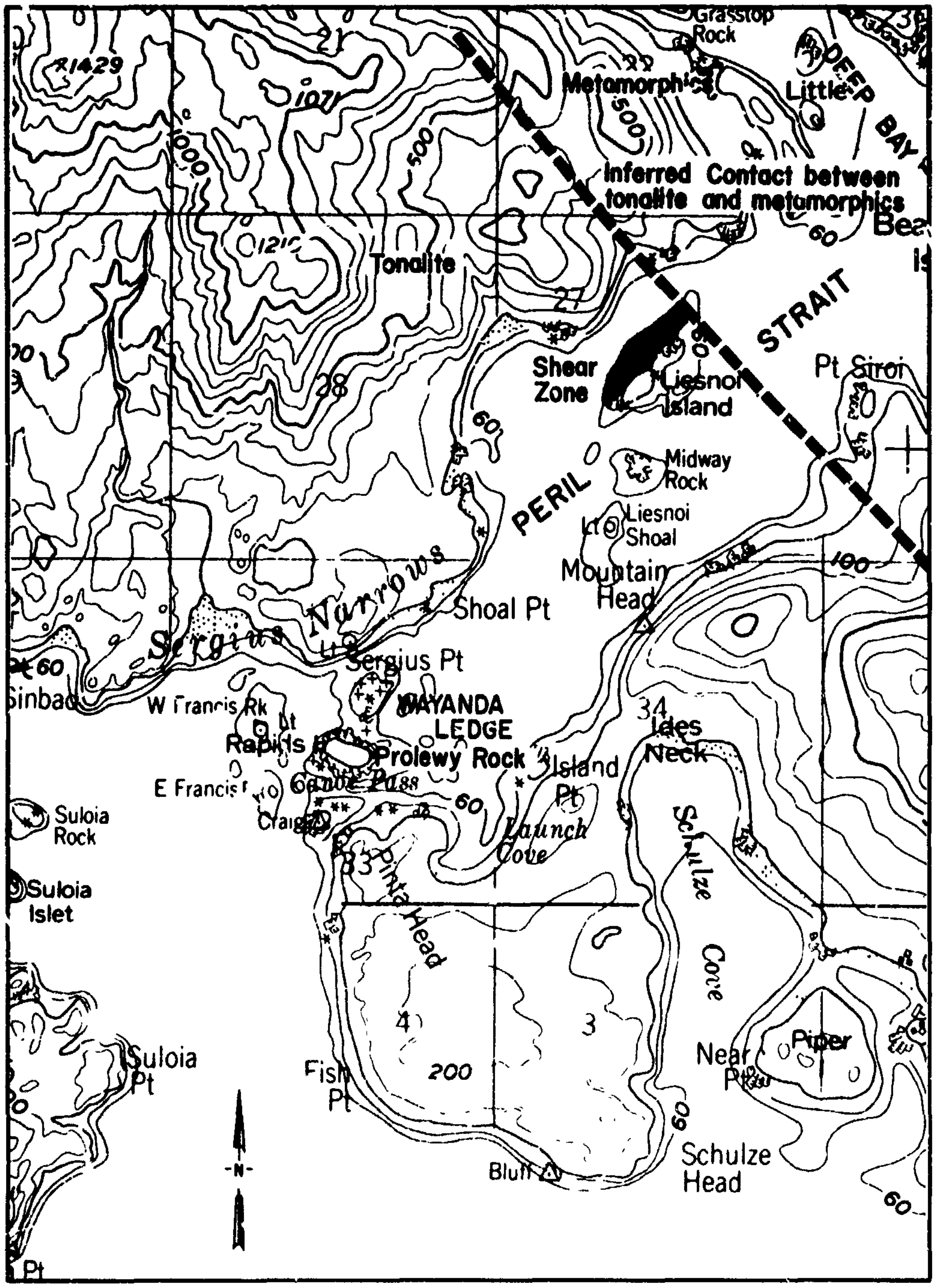


Fig. 3. Geological site map showing various rock units, location of Liesnoi Island, and shear zone adjacent to Liesnoi Island (from Ref. 6).

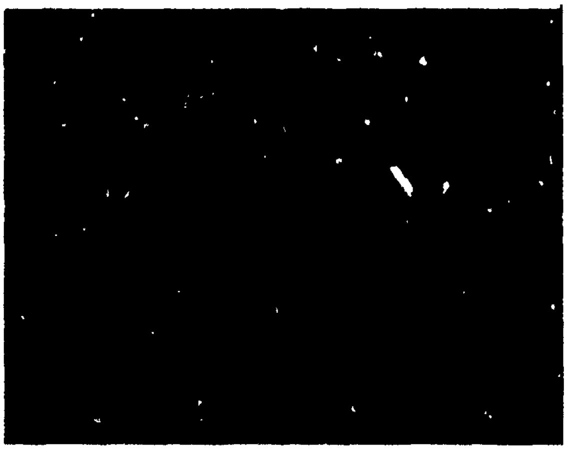


Fig. 4. Aerial view of Liesnoi Island from northeast (Roman numerals indicate charge placements).

Fig. 5. Closer aerial view of Liesnoi Island from northeast.

along weaker rocks and faults has created a series of ridges and valleys with a pronounced northwest trend. The extensive carving by the glaciers has further emphasized this trend. The predominant northwest topographic trend is occasionally cut by valleys that, in part, follow the northeast-trending fault systems.

Peril Strait cuts across one of the northwest-trending igneous plutons between Suloia Point and Liesnoi Island.

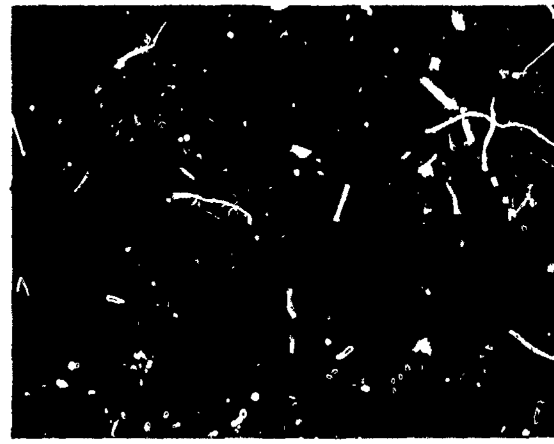


Fig. 6. Aerial view of Liesnoi Island from southwest.

The pluton is about 16 mi long and 4-1/2 mi wide, extending from Nakwasina Passage on the south to the head of Deep Bay on the north. The rock in the pluton is a foliated, hornblende tonalite (quartz diorite). The pluton will be informally referred to as the Sergius Narrows pluton in this report.

A petrographic analysis of the rock at Sergius Narrows indicates that the rock consists of 50% plagioclase, 20% hornblende, 20% quartz, and 10% biotite. Because there is no othoclase feldspar, this granite rock is classified as a tonalite or quartz diorite. The tonalite has a protoclastic texture; i.e., the grains have been broken, sheared, and rehealed on a microscopic scale. Concurrently, the rod-shaped hornblendes were rotated into a single direction (lineation) and the micas were rotated into a uniform planar direction (foliation). The foliation strikes roughly 325 deg, dipping about 45 deg west at Liesnoi Island. The lineation plunges 15 deg to the northwest in the plane of the foliation.

The pluton that encompasses Sergius Narrows is complex structurally,

consisting of the well-foliated and lineated tonalite and crossed by abundant shear zones. The shear zones are up to serveral hundred feet wide indicating intense deformation of the pluton during and after intrusion. One of the shear zones crosses the northern portion of Liesnoi Island (Fig. 6). The apparent trend of the shear zone is to the northeast. The shear zone lacks any well-defined boundaries on Liesnoi Island. Individual fractures within the shear zone appear to have two principal orientations, neither of which parallels the trend of the foliation in the tonalite (see Fig. 7).

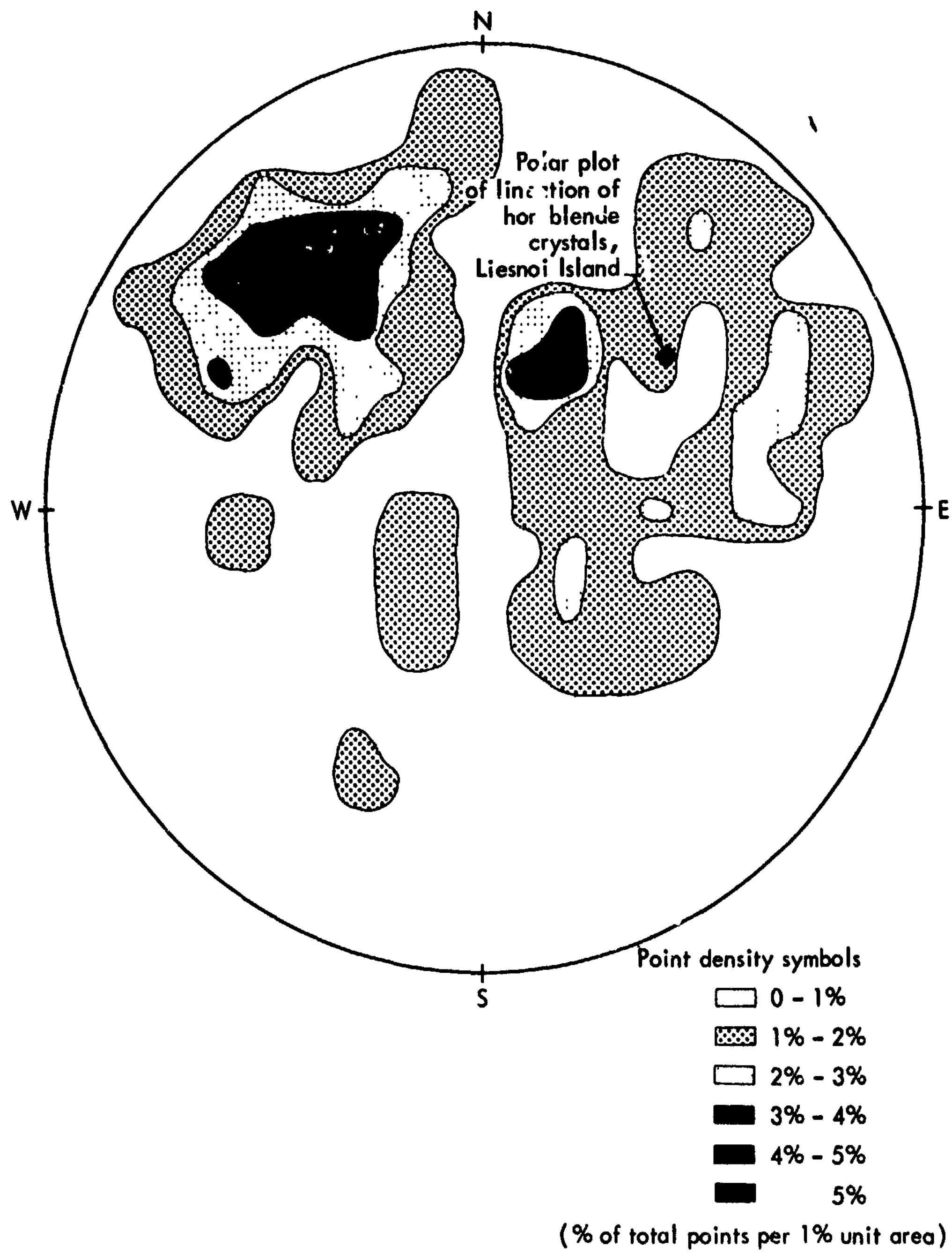


Fig. 7. Point density polar plot of all fractures found in all core from Holes IIA, IIIA, and V, Liesnoi Island.

Liesnoi Island lies along the eastern margin of the Sergius Narrows pluton. The southern part of the island consists of unsheared tonalite. The rock is hard and relatively unweathered, as evidenced by the presence of glacial striations. The northern part of the island consists of sheared and weathered tonalite, which at the surface is soft and crumbles readily; at depth the tonalite is highly fractured. Core drilling revealed the average fracture spacing to be 3 to 5 fractures per foot of core (see Appendix A). Fractures tend to be healed by quartz and epidote. Abundant small shear zones are mylonitic or partially replaced by quartz and epidote. Tests were run on selected core samples, and the results of the tests are included in Appendix B. The following are test result averages:

Apparent specific gravity	2.779
Dry density, lb/ft^3	173.46
Bulk wet density, lb/ft^3	174.78
Water content, %	0.773
Apparent specific gravity (0.044 min size)	2.869
Grain density, lb/ft^3	179.04
Porosity, %	3.144
Unconfined compressive strength, psi	9387

Based solely on the average of the laboratory tests conducted on the core taken from Liesnoi Island, the rocks at the island would be classified as a saturated, intermediate-strength rock (see Ref. 1 for discussion of media classification for explosive excavation). However, in light of the fact that the core samples tested contained numerous incipient hairline fractures and a pronounced orientation to the lineation or foliation, the low values of unconfined compressive strength may give an unrealistic picture of the rock medium. The presence of samples with unconfined compression strengths over 16,000 psi would tend to favor a high-strength classification.

Fig. 8. View of Liesnoi Island from point immediately south of overflow channel (note boulders).

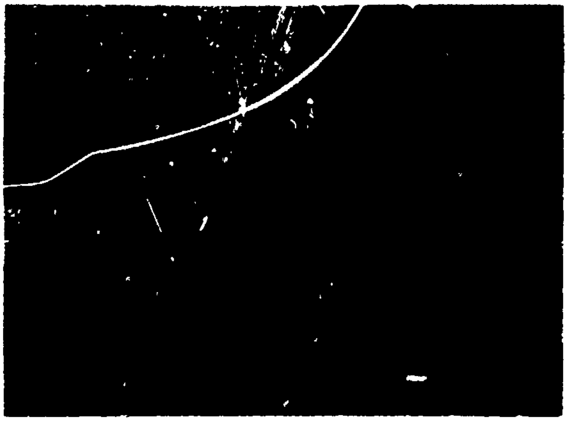


Fig. 9. View from north along east side of island.

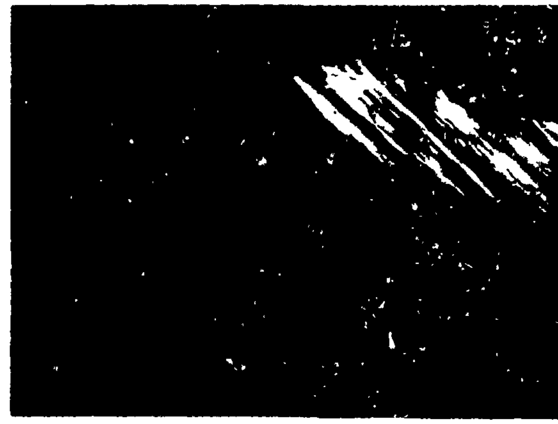


Fig. 10. View from northeast along west side of island.

Therefore, the tonalite found on Liesnoi Island will be classified as a closely jointed, saturated, intermediate-to-high-strength rock.

The topography of the test island is characterized by heavy vegetation right down to the high water line. Below this line there exists an area of large boulders, usually covered with a type of kelp and seaweed (see Figs. 8, 9, and 10).

During the test period, May through mid-July 1970, the climate was inclement. During the 63 da that NCG personnel were on site, the sun shone only for parts of 3 da. The remainder of the time the sky was overcast, and it was usually raining. The average daily temperature during the period was in the low fifties, with an average water temperature of 42°.

The average tidal range in the vicinity of Liesnoi Island was 11.2 ft with a diurnal range of 13.6 ft. The average current was 2.7 knots.

Design of Charge Layout

The tests were to include five series of detonations. In the case of each charge, the bottom of a 4- to 6-in. drill hole was to be successively sprung to the desired cavity size. Series I was to consist of springing two 5-3/4-in. diameter drill holes, 60 ft deep, to an emplacement cavity size of approximately 27-ton capacity. Series II was to consist of two separate 2-ton charges at a depth of burst (DOB) of 25 ft. One of the charges was to be fired on dry land, the other fired under water during maximum current. Series III was to consist of three 2-ton charges fired separately on sloping terrain, under water, and at different DOB's (15, 20, and 25 ft). Series IV was to consist of a double row array with three 2-ton charges in each of the rows. The in-row spacing was to be 29 ft, and the distance between rows was to be 44 ft. The DOB for the inshore row was to be 26 ft

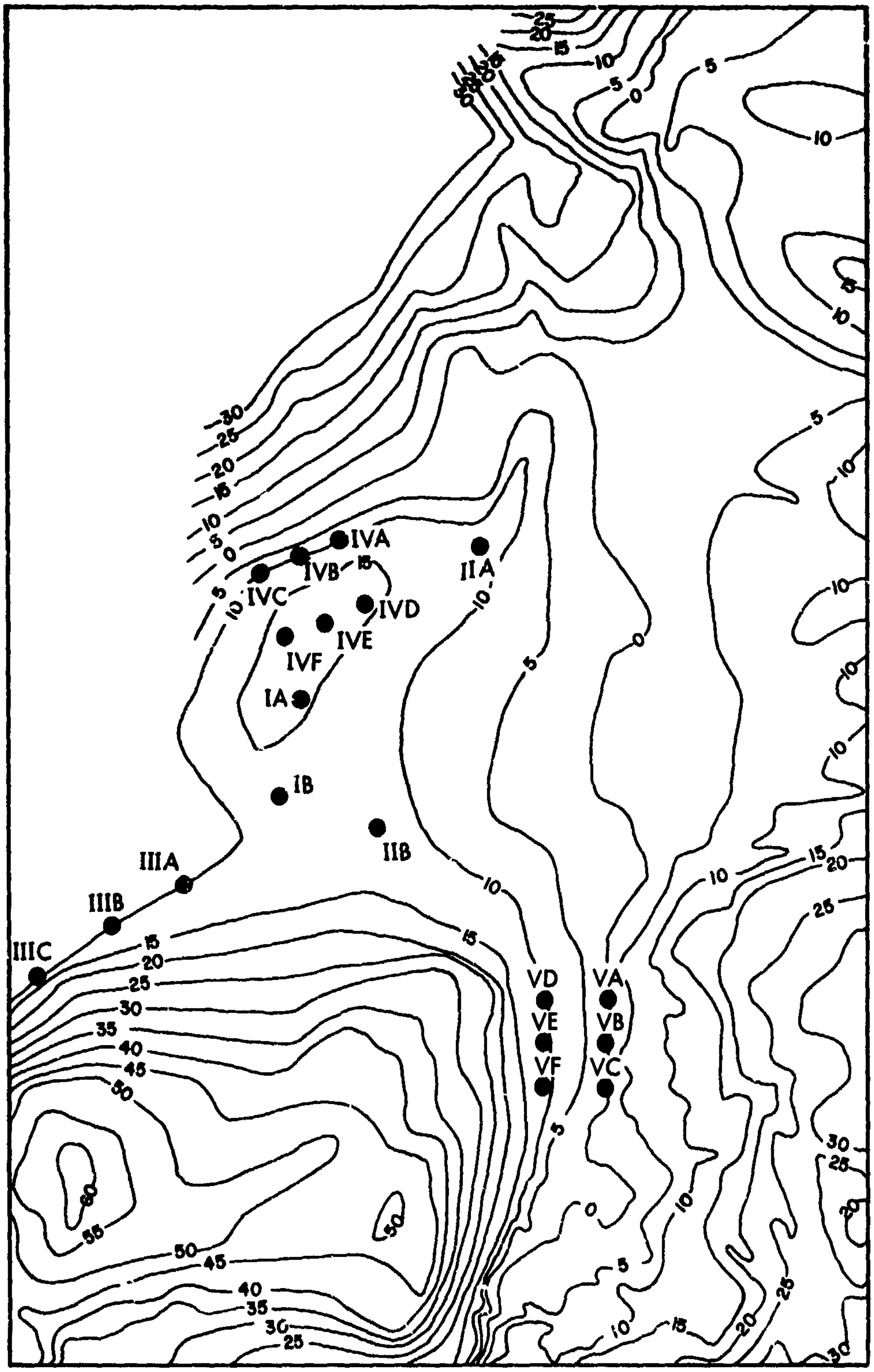


Fig. 11. Design charge layout.

and the seaward row, 21 ft. Both rows were to be detonated at the same time and with maximum water depth. Series V was again to consist of a double row array with three 2-ton charges in a row. The in-row spacing was to be 29 ft, and the distance between rows was to be 42 ft. The DOB for each charge was to be 26 ft. The seaward row was to be detonated first, and the inshore row was to be detonated 25 msec later and with a maximum water overburden.

Prior to cratering charge emplacement, each of the charge cavities was to be sprung to the desired volume. It was estimated that four springing detonations, or passes, would be required to achieve the desired cavity volume. All of the springing charges were to be placed, primed, and fired by NCG personnel.

The location of the charges in each series was to be as shown in Fig. 11. All cratering charge explosives were to be placed, primed, and fired by the explosives contractor under the supervision of the Test Manager. This charge layout would have given all the information needed about cratering phenomenology in a saturated granitic medium. Due to the high percentage of hole loss experienced during the hole springing phase, the original 18-hole test program was expanded to a final total of 57 drill holes. The program was expanded to further knowledge of hole springing and to increase the number of cratering detonations. The number of cratering detonations had been severely limited by the inability of hole springing to create cavities of sufficient size for cratering charges.

Charge Emplacement Construction

Fifty-seven holes were drilled on the island for a total drilled footage of 1383 ft. Table 1 lists the holes drilled and their depth. With the exception of Holes IIA, IIB, IIIA, IVE, and V, all holes were 4 in. in diameter and were drilled with an "Air Trac" (see Fig. 12). The excepted holes were all cored to a diameter of 5-3/4 in., and were drilled with the rotary drill pictured in Fig. 13. The logs of these holes are included as Appendix A.

Upon completion of the drilling, an attempt was made to spring each hole to the desired emplacement cavity size. The results of the springing detonations are summarized in Table 1. Of the 57 holes drilled and sprung, 14 were lost on the first pass, 8 on the second pass, 5 on the third pass, and none on the fourth pass. This represents a probability of hole failure of 0.245 with one pass, 0.386 with two passes, and 0.474 with three passes. In all cases, hole loss was caused by either block shifting as shown in Fig. 14 or extreme surface spalling as depicted in Fig. 15 through 18.

The methods and results of the Sergius Narrows hole springing operation are covered in detail in Ref. 2.

Table 1. Sergius Narrows hole springing charges.

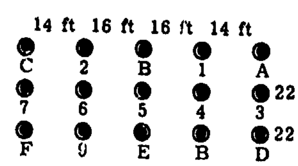
Hole	Depth (ft)	Springing charge weight-lb (vol.)				Cratering charge weight-lb (water overburden)	Remarks
		1	2	3	4		
IA	50	42 (2.0 ft^3)	–	–	–	–	Hole caved in prior to 2nd springing detonation
IB	47	28	–	–	–	–	Hole caved in by springing charge
IC	20	21 (1.7 ft^3)	70 (7.4 ft^3)	214	–	–	Extreme surface fracturing and subsurface block shifting on 3rd springing detonation
ID	41	21 (1.7 ft^3)	100 (7.4 ft^3)	214	–	–	Block shift after 3rd springing charge
IE	32.2	42 (3.9 ft^3)	226 (6.8 ft^3)	200 (22 ft^3)	–	2540, 19 boosters (dry)	Crater: depth = 61 ft; lip height = 8 ft; dia = 60 ft N-S, 100 ft E-W
IAA	49	21 (1.3 ft^3)	50 (3.9 ft^3)	150 22 ft^3	–	3400, 12 boosters (2.0 ft water)	Mound
IBB	60	21 (2.6 ft^3)	100	–	–	–	Hole completely caved in after 2d springing shot
IIA	53	50 (3.5 ft^3)	100 (8.7 ft^3)	150 (17.5 ft^3)	–	1440, 13 boosters (dry)	Crater
IIB	Redesignated IE						
IIC	40	24 (1.2 ft^3)	53 (5.0 ft^3)	103	–	–	Block displacement, surface fissures; hole lost
IIIA	25	22	–	–	–	–	The shot consisted of a triangular array, 4 ft on a side with one hole being drilled in the center: upon detonation, all holes were lost
IIIB	23	36	–	–	–	–	Two holes 4 ft on center; detonation moved a 50-ton block 20 ft seaward
IIIAA	17	21	–	–	–	–	Extreme fracturing and spalling; hole lost
IIIBB	22	21 (1.2 ft^3)	56 (3.19 ft^3)	–	–	–	Cavity collapsed due to crater IIA
IIICC	27	21 (1.2 ft^3)	56 (3.7 ft^3)	–	–	360, 8 boosters (9 ft water)	Extensive surface disruption; no crater
IVA	20	27	–[a]	–	–	1, B, 2, C loaded as a single row charge, 600, 380, 600, 500 respectively, (4-ft water overburden)	 Row 3-7 acted as a presplit row and formed the landward lip of crater, which was 40 ft wide and 80 ft long; block size ranged from 10 to 30 tons
1	20	24	53 (6.0 ft^3)	–	–		
B	20	27	53 (6.6 ft^3)	–	–		
2	20	24	53 (7.8 ft^3)	–	–		
C	20	27	53 (4.1 ft^3)	–	–		
3	20	24	53[a]	–	–	–	
4	20	27	53	–	–	–	
5	20	24	–[b]	–	–	–	
6	20	27	–[b]	–	–	–	
7	20	24	–[b]	–	–	–	
D	20	19	29	–	–	–	
8	20	7	29	53	–	–[c]	
E	20	7	29	–	–	–[d]	
9	20	7	–	–	–	–[d]	
F	20	7	29	–	–	–[d]	

Table 1 (continued)

Hole	Depth (ft)	Springing charge weight-lb (vol.) 1	2	3	4	Cratering charge weight-lb (water overburden)	Remarks
V	20	24	45	80 ($3.6\ ft^3$)	80 ($5.6\ ft^3$)	720, 12 boosters (7 ft water overburden)	Crater
VI	19	21 ($2.4\ ft^3$)	–	–	–	180, 5 boosters (4 ft water overburden)	Mound 8 ft high 50 ft diameter
VIIA	20	21	–	–	–	180 lb and 6 boosters were placed in each hole except holes A and F. Both rows were initiated instantaneously. There was a 10-ft water overburden	10 ft on center A B C D E F G H I J
B	20	21	–	–	–		
C	20	21	–	–	–		
D	20	21	–	–	–		
E	20	21	–	–	–		
F[e]	20	21	–	–	–		
G	20	21	–	–	–		
H	20	21	–	–	–		
I	20	21	–	–	–		
J	20	21	–	–	–		
VIIIA[f]	20	15	–	–	–	240 6 boosters in each hole; 6-ft water overburden	10 ft on center E D C B A J I H G F
B	20	15	–	–	–	240	
C	20	15	–		–	220	
D	20	15	–	–	–	180	
E	20	15	–	–	–	240	
F	20	15	–	–	–	220	
G	20	15	–	–	–	240	
H	20	15	–	–	–	200	
I	20	15	–	–	–	240	
J	20	15	–	–	–	280	
WC1	20	40 ($2.1\ ft^3$)	80	–	–	–	Extreme fracturing and block shifting
WC2	20	27 ($1.3\ ft^3$)	53	–	–	–	20-ft deep crater formed 10 T blocks displaced an average of 15 ft

[a]Hole lost.

[b]Holes lost due to surface disruption and block shifts.

[c]Cavity collapse.

[d]Hole lost, block shift.

[e]Lost on first pass; all others were seriously damaged, and therefore only one springing.

[f]200-msec delay between row A-E and F-J.

Fig. 12. "Air Trac."

Fig. 13. Rotary drill.

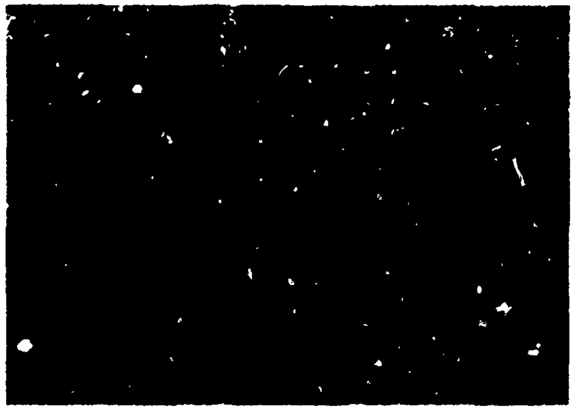


Fig. 14. Hole IIIA showing 70-ton block shifted with springing charge of 70 lb.

Fig. 15. Surface spalling at Hole IA after hole springing.

Fig. 16. Surface spalling at Hole IIA after hole springing.

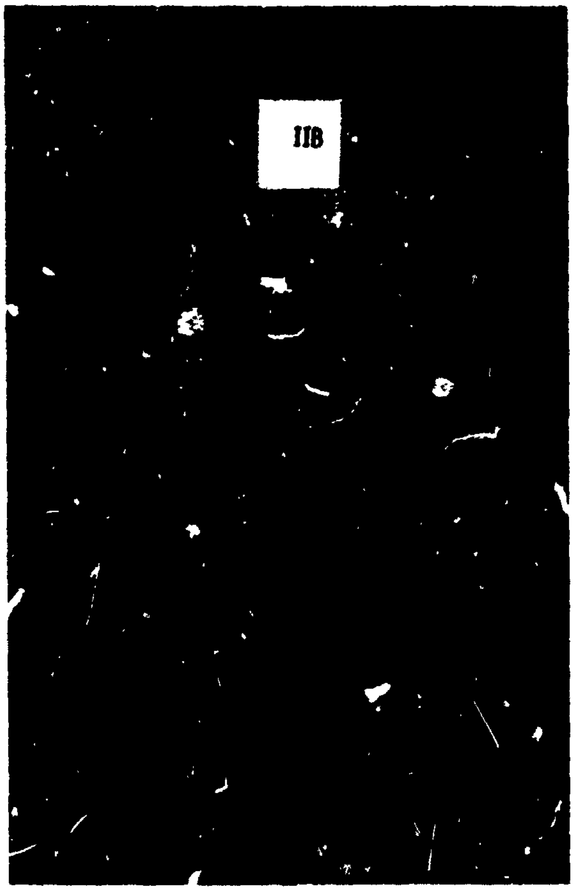


Fig. 18. Surface spalling at Hole IIIA after hole springing.

Fig. 17. Surface spalling at Hole IIB after hole springing.

Charge Emplacement and Explosives

Upon completion of the hole springing phase there were only nine single charges and arrays remaining which offered any possibility of cratering. These are listed in Table 2, along with charge weights and DOB's. The location of the charges and arrays was as shown in Fig. 19. In all cases the access hole to the charge cavity was disrupted to some degree. In over half the cases this meant that the explosive had to be cut into small pieces and fed slowly into the hole. As an example, it took 10 hr to load Charge IE with 2540 lb of explosive.

The explosives used in the Sergius Narrows Project consisted of GXL-915 and IR-10. The GXL-915 was a special explosive manufactured for the project. It had a density of 1.30 g/cm^3, a bubble energy of 875 cal/g and a detonation velocity of 4780 m/sec. This waterbased, aluminized ammonium nitrate explosive was used exclusively for hole springing. The IR-10 is an aluminized ammonium nitrate slurry which is used extensively in the Mesabi iron ranges. This oxidizer has a density of 1.24 g/cm^3, a bubble energy of 1128 cal/g, and a detonation velocity of 5450 m/sec. With the exception of two springing detonations, IR-10 was used solely for cratering detonations.

In all detonations, full column boostering was used. This meant stringing together an appropriate number of 1-lb cast

pentolite boosters. Table 2 lists the number of boosters used in each detonation. Primacord was used to initiate all detonations. Scuf-flex 60-grain primacord was used for trunk lines and 54-grain plastic reinforced primacord was used for all down lines. The primacord was initiated with No. 6 electric blasting caps.

Table 2. Sergius Narrows cratering charges.

Charge	DOB (ft)	Optimum charge weight (lb)	Actual charge weight (lb)	Number of 1-lb boosters	Water overburden (ft)
IE	28.1	8,380	2540	19	0
IAA	49	62,000	3400	12	2.0
IIA	53	74,000	1400	13	0
IIIC	27	13,200	360	8	9.0
IV1	20	2,884	600	10	4.0
IVB	20	2,884	380	10	4.0
IV2	20	2,884	600	10	4.0
IVC	20	2,884	500	10	4.0
V	20	2,884	750	12	7.0
VI	19	3,404	180	5	4.0
VIIB-F	20	2,884	180	6	10.0
VIIG-J A	20	2,884	240	6	6
B	20	2,884	240	6	6
C	20	2,884	220	6	6
D	20	2,884	180	6	6
E	20	2,884	180	6	6
F	20	2,884	220	6	6
G	20	2,884	240	6	6
H	20	2,884	200	6	6
I	20	2,884	240	6	6
J	20	2,884	280	6	6

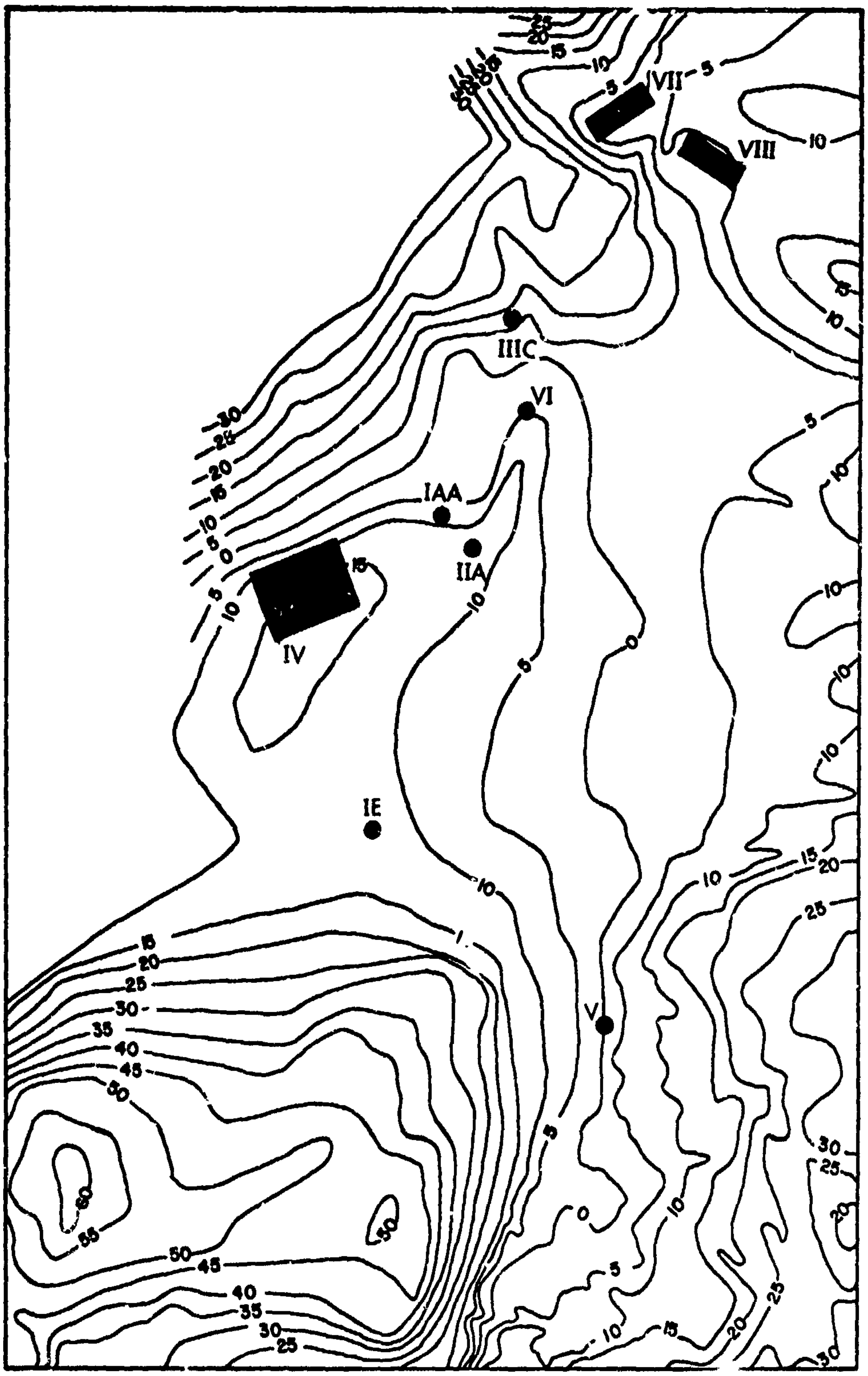


Fig. 19. Cratering charge locations.

Results

CRATER MEASUREMENTS

The Sergius Narrows cratering charges were detonated during the period 2 through 8 July 1970. Due to the problems encountered in the springing operations, as seen from Table 2, in every case the actual charge weights were considerably lower than the optimum charge weights for the DOB's indicated. The detonations, therefore, produced craters with numerous anomalies as discussed in the following paragraphs.

Charges IIA and IAA were detonated on 2 July. Charge IIA had been sprung three times and was loaded with 1,440 lb of IR-10. The resulting crater (Fig. 20) was elongated along the north-south axis and it appeared that the main force of the blast was directed along a fracture. Charge IAA also had been sprung three times and was loaded with 3,400 lb of explosive. When detonated, there was 2 ft of water over the charge. The results are depicted in Fig. 21. Whereas Charge IIA cratered, Charge IAA, at a shallow depth and a larger charge size, mounded. The mounding was a result of the hole springing. The area around Charge IIA was basically intact, therefore, containing more of the explosive energy, while the area around Charge IAA was extremely disrupted, allowing a portion of the blast energy to escape. The average block size in both detonations was 12 tons with a few blocks ranging up to 60 tons being thrown out. The maximum range of ejecta was 200 ft for Charge IAA and 300 ft for Charge IIA.

At 1545 hours on 3 July the Series IV was fired. This series was detonated as a single, four-charge row. The original series consisted of three rows of five charges. Due to hole loss, only one row remained intact after two springings. This row was loaded as shown in Table 1 and was detonated with a 4-ft water overburden. Upon detonation, rows 3 through 7 acted as a presplit line and the material moved laterally out into the channel. The resulting crater was 40 ft wide, 80 ft

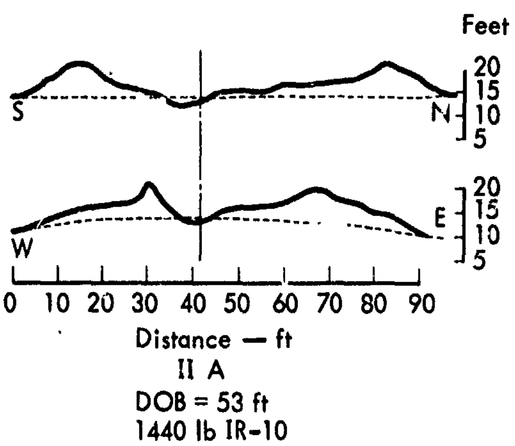


Fig. 20. Cross sections after IIA detonation

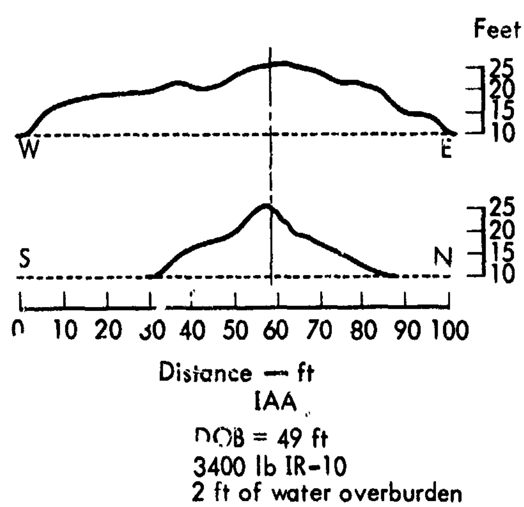


Fig. 21. Cross sections after IAA detonation

long, and had an average depth of 15 ft. There were no lips on either end or on the shoreward side. The average block size resulting from the detonation was approximately 20 tons. The maximum missile range was 500 ft, and there was a 1/2-ft water wave created which extended out to approximately 600 ft from the shot point.

Charge IE was detonated at 1645 hours on 5 July. The results were as depicted in Fig. 22. The charge cavity had been sprung three times and then was loaded with 2,540 lb or IR-10. There was no water overburden. As with Charge IIA, the main force of the charge was directed along fracture lines resulting in the greatest crater diameter being on a NNW-SSE line. There was very definite lip formation along the WSW axis with no apparent lip formation along the orthogonal axis. The average block size was again 12 tons with a maximum size of 50 tons. The maximum missile range was 400 ft.

Charge IIICC was intended to be a cratering detonation and was fired at 1715 hours on 5 July. However, it turned out to be a springing detonation, but on too large a scale. The surface rock was completely shattered and blocked the entrance into the cavity. The cavity had been sprung twice and accepted only 260 lb of explosive when loaded for cratering. Prior to the detonation, the area surrounding the drill hole was extremely disrupted, and it was feared that one more springing shot would collapse it completely. At the time of detonation there was a 9-ft water overburden.

On 6 July at 1000 hours Charge VI was detonated. It was intended that this charge would give preliminary indication of expected results for the Series VII and VIII. All previous holes had been sprung successively (i.e., more than once); therefore, it was decided to attempt to spring a hole with a single small charge and then to load it full for final detonation. If the results were at all acceptable, the same procedure would be followed for the Series VII and VIII holes. After one springing shot, it was found that Hole VI would accept 180 lb of explosive. This was detonated with a 4-ft water overburden. Upon detonation a mound of rock was created 8 ft higher than the original ground surface with a mean diameter of 50 ft. The maximum missile throw was less than 100 ft.

Due to the results of the Charge VI detonation, the same procedure was followed on Series VII. After one springing pass, one hole was lost and the other nine were extremely damaged. In order to preserve the array, as pictured in Table 1, only eight of the holes were loaded. These were loaded with 180 lb each and fired simultaneously at 1800 hours on 7 July with a 10-ft water overburden. The results of the detonation

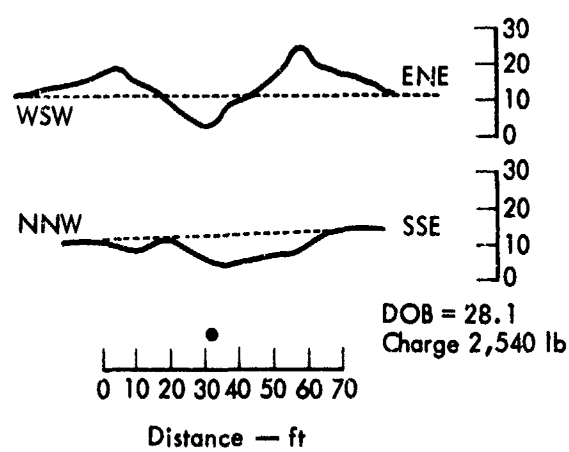


Fig. 22. Cross sections after IE detonation

are shown in Fig. 23. The breakage appeared good with the maximum block size only about 10 tons. There was a definite lip formation along the shoreward side of the rows with a small lip formed at one end of the crater. The preponderance of the material was thrown laterally into the deep channel area to the northwest. The maximum missile throw was 200 ft.

As one hole had been lost in springing the Series VII, it was decided to reduce the springing shot for the Series VIII to

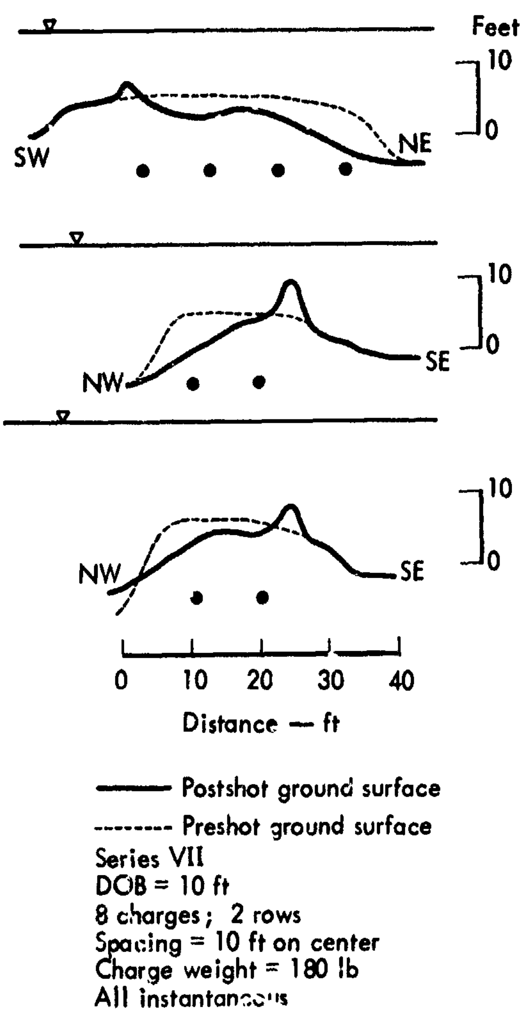


Fig. 23. Cross sections after Series VII detonation

15 lb. This resulted in no hole loss although there was extreme surface disruption. Each hole was then loaded to as near full as possible. The individual loads were as shown in Table 1.

Series VIII was detonated at 1635 hours on 8 July. The results of this detonation are depicted in Fig. 24. The landward row was detonated 200 msec after the seaward row. This along with the slightly larger charge sizes, gave a larger crater volume than was the case in the Series VII. It also increased the lateral throw of the ejecta as evidenced by the more pronounced lip formation on the seaward side. The breakage for Series VIII was about the same as for the Series VII. However, missile throw was greater, about 350 ft, and was very directional—toward the sea.

The Charge V emplacement hole had been sprung four times. The springing detonations had opened up surface fractures and had not resulted in a very large cavity. The cavity would accept only 720 lb of explosive when loaded. This was detonated on 8 July with a 7-ft water overburden. There was a small crater produced by the detonation but it appeared to result mainly from surface spalling. The results appeared to be much like those of Charge IIIC; i.e., the charge was too small for cratering and too large for springing.

Of the six single-charge cratering detonations fired on Liesnoi Island, only two produced apparent craters. These were Detonations IE and IIA. The results of these detonations have been scaled and are plotted on the dry rock cratering curve, Fig. 5 of Ref. 7 (see Fig. 25).

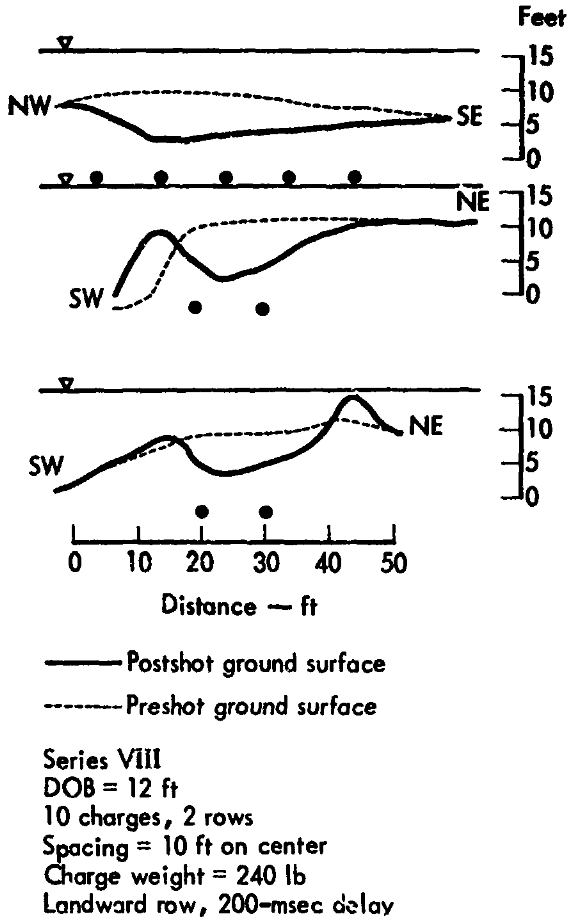


Fig. 24. Cross sections after Series VIII detonation

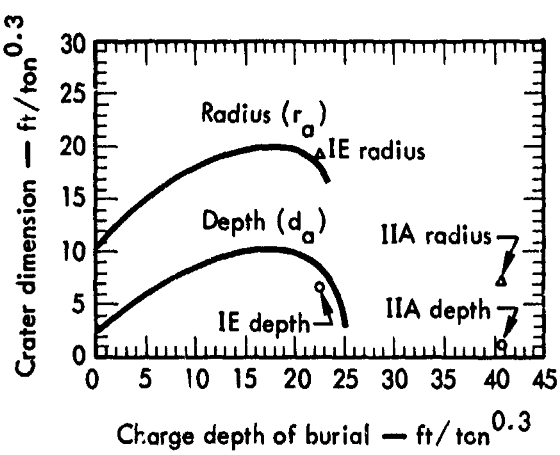


Fig. 25. Sergius Narrows results superimposed on dry rock cratering curve from Ref. 7.

PRESSURE MEASUREMENT PROGRAM

The pressure measurement program was conducted by NCG and consisted of the use of Dunegan pressure gages at various distances from three of the detonations. The location of gages and results were as depicted in Fig. 26. The results of the pressure measurement program were generally inconclusive because the pressures involved were generally less than the gage threshold.

FISH AND GAME DEPARTMENT PROGRAM

The fish kill program was conducted by the Bureau of Commercial Fisheries and the Alaska Department of Fish and Game. The fish and game program consisted of putting live fish in underwater cages at varying distances from the detonations. The cages were placed at 20, 50, 100, 200, and 500 meters from Charges VII and VIII. There were no fish killed in the cages as a result of the detonations.

The Bureau of Commercial Fisheries Program also surveyed the marine animals in the vicinity of the blasts. This survey was made prior to and after the cratering phase. In general, the surveys indicated no large-scale destruction of invertebrates or fish. The only apparent mortalities were a few sea stars and one sea cucumber. One vertical bedrock surface, about 6 ft by 4 ft, was found that looked as though it had been scraped; that is, the normal growth of invertebrates was missing but corraline algae and other tightly attached organisms were still present. Many of the missing animals were lying at the bottom at the vertical

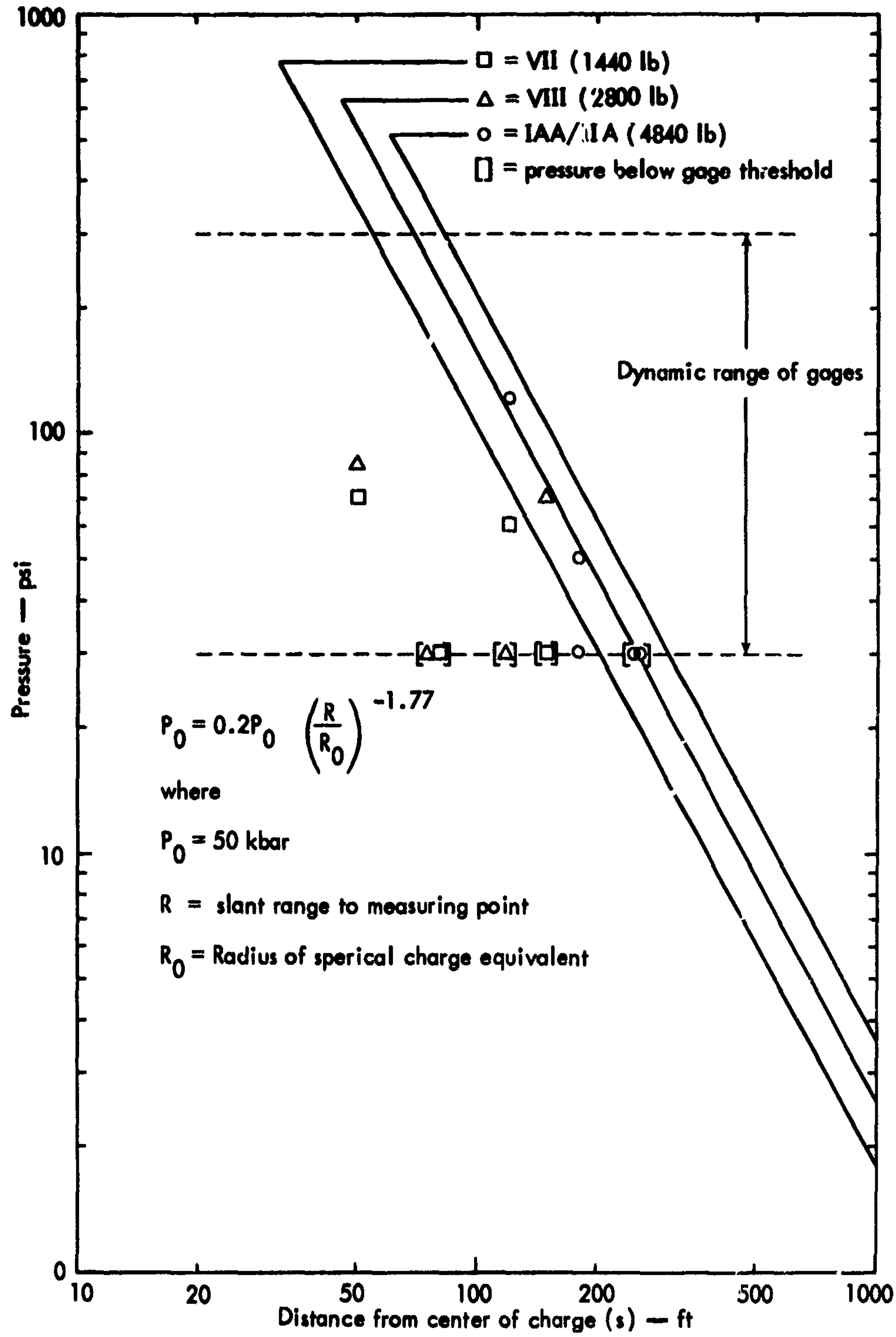


Fig. 26. Pressure measurements made in water.

face, as though they had slid down after being dislodged. Normal invertabrate growths covered adjacent rock surfaces.

Large numbers of various species of rockfish were present after the tests on both shores. Other animals, which

appeared to be present in normal numbers, were sculpins, brittle stars, various species of starfish, sea cucumbers, green sea urchins, purple sea urchins, basket starts, and gorgonians. State biologists found a few dead rockfish and salmonoids along the shores of Liesnoi Island.

Summary and Conclusions

The results of the Sergius Narrows hole springing detonations were invaluable in adding to the knowledge in the field. Conclusions from the springing results are covered in detail in Ref. 2. To summarize these conclusions, the hole springing of charge cavities is extremely medium-dependent. As the strength of the rock increases, the probability of hole loss increases, This probability of loss is also increased as the springing charge weight is increased. Therefore, when an explosive excavation design depends on a fairly rigid charge location and size criteria, hole springing in intermediate- or high-strength rock does not appear to be economical or feasible. In these types of medium, under-reaming or full-diameter drilling should be used to construct the charge cavity.

Due to the failure of hole springing there were minimal cratering results which could be used to generate design data. Each of the charge cavities produced was much smaller than that required at the particular depth. However, even though the charge weights were much lower than optimum,(Table 2), two of the charges did crater and one produced a mound. From the results achieved by Detonations IEE, IAA, and IIA, it appears that the current cratering data for dry rock may be conservative and consequently could be used for explosive excavation design in a saturated, intermediate-to-high-strength medium with some expected overexcavation. The detonation of the three-row arrays indicates that directional blasting is a valid concept where there is a free surface such as a shoreline. Utilizing a delay, it is possible to increase this directional effect. In all the detonations on Liesnoi Island, large blocks were in evidence. This, coupled with the absence of lips on some craters, was a direct result of the jointing pattern. In order to achieve reliable cratering data in this medium, it would have been necessary to use larger charges, which would have tended to alleviate the effect of these large blocks on the crater dimensions.

Finally, it can be concluded that there was little effect on marine life as a result of the detonations. Larger explosive charges or a different geological structure could conceivably result in more significant damage to the littoral area, but it appears that when detonations occur in a rock mass under water the detonation-induced damage to marine life is of extremely limited range.

The information collected during the experiment showed that current design information for this type of medium is conservative. It also showed that in this type of medium, hole springing is risky at best. Therefore, the experimental project did achieve its design objectives.

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Appendix A

Core Logs for Project Sergius Narrows, Liesnoi Island, Alaska

BORING NUMBER: IIA	SHEET 1 OF 2
LOCATION:	
ANGLE OF BORING: Vertical	TYPE OF BORING: 6", 4"
BEARING:	DRILLING AGENCY: Alaska District
SURFACE ELEVATION:	TOTAL DEPTH: 33.0'
TOTAL CORE RECOVERY: 100%	WATER TABLE DEPTH: Variable with tide
HOLE STARTED 3 June 1970	HOLE COMPLETED 4 June 1970

ELEV. (FT)	DEPTH (FT)	LOG	DESCRIPTION	% CORE RECOV. 0 100	FRACTURE LOG Mid-point	Dip Degrees
	0					
	1.8		Hornblende tonalite: well-foliated, strike N 7°W dip 60 SW. Approximately 20% hornblende, 5% biotite, rest plagioclase and quartz. Abundant joints and shears.			60 20 30 60
	2.9					65
			Sheared zones, healed by epidote and quartz.			30 90
	5					
	6.3 6.4		Sheared zone, 1-1/2 inches thick, healed by epidote and quartz.			57 34
	7.1		Rubble, 2 - 4 inches in diameter, composed mostly of sheared tonalite and quartz and epidote vein material.			33 70 35
	9.4		Rubble, 2 - 4 inches in diameter.			
	10					
	10.9		Rubble, sand size to 2 inches.			60 75 72 35 70
	14.0		Rubble, 1 - 4 inches in diameter.			40 55
	15		Foliation dips 65°			64 55 30
	16.9		Sheared tonalite, quartz and epidote vein 1-1/2 inches thick.			55 37 60 65
	18.4		Sheared zone 3" thick.			
	19.2		Sheared zones, 2" thick.			35
	20		Foliation distorted about the shear zones.			
	21.6		Mylonite			25 38 35 5
	24.3		Sheared zone, offset along a joint			

BORING NUMBER: TTA SHEET 2 OF 2 FRACTURE LOG

ELEV. (FT)	DEPTH (FT)	LOG	DESCRIPTION	% CORE RECOV. 0 100	MID-POINT	Dip Degrees
	25					
	25.4		Shear zone			40
						35
	26.8					
			Shear zone 1/8 inch wide.			65
	28.8		Sheared tonalite and epidote, 5 inches thick.			
	30					
						45
	33.0					30

BORING NUMBER: II B	SHEET 1 OF 2
LOCATION:	
ANGLE OF BORING: Vertical	TYPE OF BORING: 6", 4"
BEARING:	DRILLING AGENCY: Alaska District
SURFACE ELEVATION:	TOTAL DEPTH. 2.3
TOTAL CORE RECOVERY:	WATER TABLE DEPTH: Variable with tide
HOLE STARTED 5 June 1970	HOLE COMPLETED 8 June 1970

ELEV. (FT)	DEPTH (FT)	LOG	DESCRIPTION	% CORE RECOV. 0 100	FRACTURE LOG Mid-point	Dip Degrees
	0		Soil and rubble overburden			
	2.5		Hornblende tonalite, well foliated, composed of 75% quartz and plagioclase, 20% hornblende and 5% biotite. Crossed by numerous veins of quartz and epidote. Hard, unweathered. Foliation dips 45°.			
	4.5					75
						25
	5		Rubble zone, clasts 2 - 5 inches.			
						25
						50
	7.6		Rubble zone, clasts 2 - 5 inches. Sheared tonalite, quartz and epidote clasts.			
	9.2		Shears, 1/8 inch wide.			
	9.6					
	10					
	10.2					
	10.7		Shear zone 1 inch wide.			
	11.1		Shear zones, 2 inches wide.			
						30
						45
						55
						65
	15					65
						30
						40
						35
			Shear zone, with epidote. Aplite band.			50
	20					40
						60
						15
						60
						40
	24.1		Shear zone, with epidote.			
	24.6		Shears			
	24.8					

BORING NUMBER: IIB			SHEET 2 OF 2			FRACTURE LOG
ELEV. (FT)	DEPTH (FT)	LOG	DESCRIPTION	% CORE RECOV. 0 100	MID-POINT	Dip Degrees
	25					
	25.2		Shear			40
	27.9		Shear			
	29.0		Shear zone, 5 inches thick.			
	29.9					
	30					60
			Shear zone, 1/2 inch wide..			
	32.3					55

BORING NUMBER: III A	SHEET 1 OF 1
LOCATION:	
ANGLE OF BORING: Vertical	TYPE OF BORING: 6", 4" Core
BEARING:	DRILLING AGENCY: Alaska District
SURFACE ELEVATION:	TOTAL DEPTH: 20.5
TOTAL CORE RECOVERY:	WATER TABLE DEPTH: Variable with tide
HOLE STARTED 10 June 1970	HOLE COMPLETED

ELEV. (FT)	DEPTH (FT)	LOG	DESCRIPTION	% CORE RECOV. 0 100	FRACTURE LOG Mid-point	FRACTURE LOG Dip Degrees
	0		Rubble. Boulders are weathered remnants of solid bedrock, still in their original positions. Weathering along joints has reduced the strength of the mass to that of a pebble pile.			
	4.7		Top of solid rock.			
	5		Hornblende tonalite, well foliated, strike N 58° W dip 51 S. 25% hornblende, 5% biotite, 70% quartz and plagioclase, minor magnetite.			50, 35, 45, 35
			Mylonite lens, parallel the foliation.			51, 15
			Mylonite lens.			50, 45, 65, 40, 55
			From 9.6 to 10.1 feet is a wedge of lighter-colored rock-80% quartz and plagioclase			25
	10					35
	11.3		Sheared zone, with epidote.			85, 50
						75, 50, 50, 70, 60
			Rock more weathered between about 13 and 15 feet. Also have slight banding of light and dark rock.			
	15					
						70, 20
						60
						55
	20					

BORING NUMBER: IV E	SHEET 1 OF 2
LOCATION:	
ANGLE OF BORING: Vertical	TYPE OF BORING: 6", 4" Core
BEARING:	DRILLING AGENCY: Alaska District
SURFACE ELEVATION:	TOTAL DEPTH: 30.0 feet
TOTAL CORE RECOVERY:	WATER TABLE DEPTH: Variable with tide
HOLE STARTED 15 June 1970	HOLE COMPLETED 16 June 1970

ELEV. (FT)	DEPTH (FT)	LOG	DESCRIPTION	% CORE RECOV. 0 100	FRACTURE LOG Mid-point	Dip	Degrees
	0		Loose rubble in top 2.5 feet. Boulders to 0.5 feet, mostly arount 0.2 feet. Below 2.5 boulders are to 0.9 feet; they are probably remnants of weathering along joints in the bedrock.				
	5		Hornblende tonalite. 10% biotite in clumps to 1 cm; 15% hornblende to 1 cm long; 75% quartz and biotite. Well-foliated, no outcrops at the			40	
	8.5		Vertical shear zone truncated by small faults.				
	10		Shear zone			70	
			Shear			40 60	
	13.7		Rubble zone. Rock disintegrates readily.				
	15		Many shear zones from 15 feet to bottom of hole			45	
						55	
			Shears dipping 80° across the foliation. 1/2 - 1 inch thick, with mylonitic material in them.				
	20						
						65	
			Mylonite zone, 2 inches thick.				
			Shear zone.				

BORING NUMBER: IV E			SHEET 2 OF 2		FRACTURE LOG		
ELEV. (FT)	DEPTH (FT)	LOG	DESCRIPTION	% CORE RECOV. 0 100	MID-POINT	Dip	Degrees
	25						
			Wide shear zone. Well-rehealed, core solid from 25.8 to 30.0 feet.				
	30.0						

BORING NUMBER: V D	SHEET 1 OF 2
LOCATION:	
ANGLE OF BORING: Vertical	TYPE OF BORING: 6", 4" Core
BEARING:	DRILLING AGENCY: Alaska District
SURFACE ELEVATION:	TOTAL DEPTH: 31.0 feet
TOTAL CORE RECOVERY:	WATER TABLE DEPTH: Variable with tide
HOLE STARTED 12 June 1970	HOLE COMPLETED 13 June 1970

ELEV. (FT)	DEPTH (FT)	LOG	DESCRIPTION	% CORE RECOV. 0 100	FRACTURE LOG Mid-point	Dip Degrees
	0		Loose rubble, boulders and pebbles.			
			Top of solid rock.			
			Hornblende biotite tonalite. Well foliated, 8% biotite, 17% hornblende, 25% quartz, 50% plagioclase. Lenses of both mafic and felsic segregations (enoliths?). Foliation strikes N 42°W, dip 62 SW.			55
						65
						30
	5					55
			Shear zone.			50
						70
						30
						45
	10					20
						25
						50
						35
	14.2		Rock is weathered to 16.9 feet. Splits readily along the foliation.			40
						30
	15					70
						65
						60
						60
	20					25
						55
						50
						50
						60
						75
						60

BORING NUMBER: V D			SHEET 2 OF 2		FRACTURE LOG	
ELEV. (FT)	DEPTH (FT)	LOG	DESCRIPTION	% CORE RECOV. 0 100	MID-POINT	Dip Degrees
	25					45
						35
						10
						70
						80
						80
						35
	30					
						15
	31.0					

Appendix B
Tests of Sergius Narrows Core

District Engineers Laboratory Report
TESTS OF SERGIUS NARROWS CORE
Samples for Nuclear Cratering Group

DE Lab File Number 71-57 2 November 1970

CORE SAMPLES TESTED

1. Hole No. IIB, depth 24.9' to 25.1'
2. Hole No. IIB, depth 25.1' to 25.3'
3. Hole No. IIIA, depth 18.4' to 18.6'
4. Hole No. IIIA, depth 18.6' to 18.8'
5. Hole No. IV, depth 15.3' to 15.5'
6. Hole No. VD, depth 24.7' to 24.9'
7. Hole No. VD, depth 24.9' to 25.1'
8. Hole No. VD, depth 25.1' to 25.3'

TESTS REQUESTED

1. Bulk wet density
2. Dry density
3. Water content
4. Grain density
5. Porosity
6. Unconfined compressive strength

TEST PROCEDURES:

1. Sample Preparation: Samples, as received, were placed in the damp room for a period of one week to replace moisture lost in drilling and lost in handling from the field to the laboratory. The samples were sectioned with a diamond saw, utilizing water as a cutting agent. The water content and the bulk wet density was determined on saturated sections. The remaining tests were conducted on samples dried to constant weight at a temperature of 190°F. Test surfaces for unconfined compressive strength tests were polished to insure parallel surfaces. The distorted structure and the presence of numerous incipient hairline cracks in each sample dictated the orientation and the number of unconfined compressive strength tests.

2. Moisture content and specific gravities were determined in accordance with ASTM Test Designation C97-47.

Unit weights were calculated.

3. Unconfined compressive strength tests were determined in accordance with ASTM Test Designation C170-50, utilizing 2" x 2" cubes.

4. The apparent specific gravity and grain density was determined on dry core material, mechanically reduced to a maximum grain size of 0.044mm and tested in accordance with ASTM Test Designation C128.

TEST RESULTS

1. CORE HOLE NO. IIB.

Depth	24.9' to 25.1'
Apparent Specific Gravity	2.695
Dry Density	168.17 lbs/ft^3
Bulk Wet Density	170.93 lbs/ft^3
Water Content	1.645%
Apparent Specific Gravity (-0.044mm size)	2.721
Grain Density	169.79 lbs/ft^3
Porosity	0.961%
Unconfined Compressive Strength	5,199 psi Lineation distorted. Load applied parallel to healed shear planes.

TEST RESULTS (CONTINUED)

2. CORE HOLE NO. IIB.

Depth	25.1' to 25.3'
Apparent Specific Gravity	2.754
Dry Density	171.85 lbs/ft^3
Bulk Wet Density	173.55 lbs/ft^3
Water Content	0.991%
Apparent Specific Gravity (-0.044mm size)	2.872
Grain Density	179.21 lbs/ft^3
Porosity	4.166%
Unconfined Compressive Strength	3,697 psi Lineation highly distorted. Load applied parallel to healed shear planes.

3. CORE HOLE NO. IIIA.

Depth	18.4' to 18.6'
Apparent Specific Gravity	2.862
Dry Density	178.65 lbs/ft^3
Bulk Wet Density	179.45 lbs/ft^3
Water Content	0.447%
Apparent Specific Gravity (-0.044mm size)	2.956
Grain Density	184.45 lbs/ft^3
Porosity	3.205%
Unconfined Compressive Strength	6,950 psi Weak lineation. Load applied parallel to lineation.

TEST RESULTS (CONTINUED)

4. CORE HOLE NO. IIIA.

Depth	18.6' to 18.8'
Apparent Specific Gravity	2.841
Dry Density	177.29 lbs/ft^3
Bulk Wet Density	178.24 lbs/ft^3
Water Content	C.536%
Apparent Specific Gravity (-0.044mm size)	2.957
Grain Density	184.51 lbs/ft^3
Porosity	4.006%
Unconfined Compressive Strength	11,125 psi Weak lineation. Load applied perpendicular to healed shear and perpendicular to lineation.

5. CORE HOLE NO. IV.

Depth	15.3' to 15.5'
Apparent Specific Gravity	2.707
Dry Density	168.91 lbs/ft^3
Bulk Wet Density	171.62 lbs/ft^3
Water Content	1.608%
Apparent Specific Gravity (-0.044mm size)	2.754
Grain Density	171.85 lbs/ft^3
Porosity	1.762%
Unconfined Compressive Strenth	7,127 psi Specimen distorted - no lineation apparent. Main shear zone recemented. Load applied perpendicular to major shear zone.

TEST RESULTS (CONTINUED)

6. CORE HOLE NO. VD.

Depth -- 24.7' to 24.9'

Apparent Specific Gravity -------------------- 2.781

Dry Density ---------------------------------- 173.53 lbs/ft^3

Bulk Wet Density ----------------------------- 174.11 lbs/ft^3

Water Content -------------------------------- 0.338%

Apparent Specific Gravity (-0.044mm size) ----- 2.8[illegible]2

Grain Density -------------------------------- 177.96 lbs/ft^3

Porosity ------------------------------------- 2.564%

Unconfined Compressive Strength --------------- 18,733 psi
Load applied parallel
to lineation.

7. CORE HOLE NO. VD.

Depth -- 24.9' to 25.1'

Apparent Specific Gravity -------------------- 2.797

Dry Density ---------------------------------- 174.53 lbs/ft^3

Bulk Wet Density ----------------------------- 175.05 lbs/ft^3

Water Content -------------------------------- 0.302%

Apparent Specific Gravity (-0.044mm size) ----- 2.893

Grain Density -------------------------------- 180.52 lbs/ft^3

Porosity ------------------------------------- 3.365%

Unconfined Compressive Strength --------------- 11,521 psi
Load applied parallel
to lineation.

TEST RESULTS (CONTINUED)

8. CORE HOLE NO. VD.

Depth -- 25.1' to 25.3'

Apparent Specific Gravity -------------------- 2.801

Dry Density ---------------------------------- 174.78 lbs/ft^3

Bulk Wet Density ----------------------------- 175.34 lbs/ft^3

Water Content -------------------------------- 0.324%

Apparent Specific Gravity (-0.044mm size) ----- 2.950

Grain Density -------------------------------- 184.08 lbs/ft^3

Porosity ------------------------------------- 5.128%

Unconfined Compressive Strength --------------- 10,750 psi
Load applied
perpendicular
to lineation.

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